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Inclusive B decays and exclusive radiative decays by Belle

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The $b \rightarrow s\gamma$, $b \rightarrow d\gamma$ and $b \rightarrow s\ell^+\ell^-$ processes are allowed at higher order via the electroweak loop or box diagrams in the Standard model. It is sensitive probe to search for new physics beyond the Standard model because new particles might enter in the loop.

We present preliminary results of branching fraction of the $\overline{B} \rightarrow X_s\gamma$, CP asymmetry in the $\overline{B} \rightarrow X_{s+d}\gamma$, and the forward-backward asymmetry in the $\overline{B} \rightarrow X_s\ell^+\ell^-$. The results are based on a data sample containing $772 \times 10^6 B\overline{B}$ pairs recorded at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB e^+e^- collider.

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1 Introduction

The $b \rightarrow s\gamma$, $b \rightarrow d\gamma$ and $b \rightarrow s\ell^+\ell^-$ processes are allowed at higher order via the electroweak loop or box diagrams in the Standard model (SM). It is sensitive probe to search for new physics beyond the SM because new particles might enter in the loop. In this report, we present results of inclusive or semi-inclusive measurements about electroweak penguin processes. Inclusive measurement are preferable to exclusive measurements because of lower theoretical uncertainties, although they are experimentally more challenging.

2 Branching Fraction of the $\overline{B} \rightarrow X_s\gamma$

For this analysis a “sum of exclusive” approach is chosen, i.e. we measure as many exclusive X_s modes as possible and then sum them up to extrapolate inclusive branching fraction. We reconstruct the B meson from a high energy photon and one of the 38 X_s final states. We require the photon candidate with energy $1.8 \text{ GeV} < E_\gamma^* < 3.4 \text{ GeV}$ in the center-of-mass (CM) frame.

The dominant background comes from $e^+e^- \rightarrow q\bar{q}(u, d, s, c)$ continuum events, which is suppressed using mainly event shape information. For an effective background rejection, we employ a neural network based on the software package “NeroBayes” package [1]. When π^0 from the ρ emits a high energy photon in the $B \rightarrow D^{(*)}\rho^+$ decay, it looks like the signal. To veto such backgrounds, we reconstruct D candidates of the major decay modes with combinations of particles used in the X_s reconstruction, and veto events with reconstructed D mass close to the nominal D mass.

The signal yields are extracted by an maximum likelihood fit to the beam-constrained mass, M_{bc} . To minimize the systematic uncertainty from modeling of the X_s mass distribution, we divide the data into 19 bins of X_s mass in the region $0.6 \text{ GeV}/c^2 < M_{X_s} < 2.8 \text{ GeV}/c^2$. Maximum X_s mass corresponds to a minimum photon energy of 1.9 GeV. Figure 1 shows the partial branching fraction as a function of M_{X_s} . Total branching fraction in $M_{X_s} < 2.8 \text{ GeV}/c^2$ is obtained from the sum of 19 M_{X_s} bins:

$$\mathcal{B}(\overline{B} \rightarrow X_s\gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}, \quad (1)$$

where the first uncertainty is statistical and the second is systematic. To compare theoretical prediction, the experimental result is extrapolated to photon energy in the B rest frame above 1.6 GeV with extrapolation factor [2]:

$$\mathcal{B}(\overline{B} \rightarrow X_s\gamma) = (3.74 \pm 0.18 \pm 0.35) \times 10^{-4}, \quad (2)$$

which is consistent with SM prediction [3] within 1.3σ and the most precise result of any sum-of-exclusives approach.

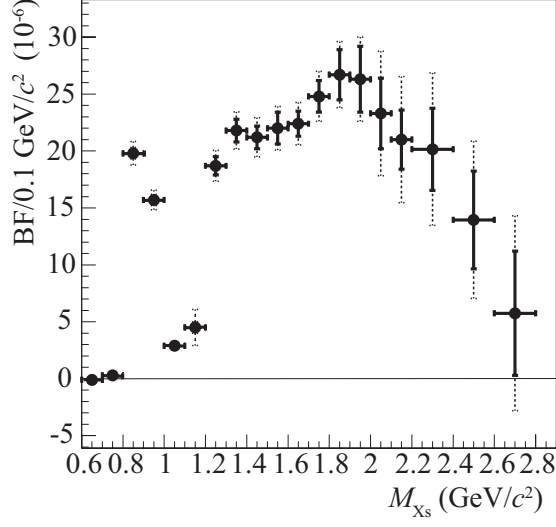


Figure 1: Partial branching fraction as a function of M_{X_s} . The error basrs correspond to the statistical (solid) and the quadratic sum of the statistical and systematic (dashed).

3 CP asymmetry in the $\overline{B} \rightarrow X_{s+d}\gamma$

The CP asymmetry (\mathcal{A}_{CP}) in the $\overline{B} \rightarrow X_{s+d}\gamma$ decays is defined as:

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B} \rightarrow X_{s+d}\gamma) - \Gamma(B \rightarrow X_{\overline{s}+\overline{d}}\gamma)}{\Gamma(\overline{B} \rightarrow X_{s+d}\gamma) + \Gamma(B \rightarrow X_{\overline{s}+\overline{d}}\gamma)}. \quad (3)$$

In the SM, $\mathcal{A}_{CP}(\overline{B} \rightarrow X_{s+d}\gamma)$ is predicted to be zero with negligible theoretical uncertainty [4]. In this analysis, we reconstruct only high energy photon with an CM energy $1.4 \text{ GeV} < E_\gamma^* < 2.8 \text{ GeV}$ from signal- B decay and perform a fully inclusive measurement. To identify the flavor of signal- B meson, we use charge of a lepton, which comes from semileptonic decay of opposite B meson. We require lepton momentum with $1.10 \text{ GeV} < p_\ell^* < 2.25 \text{ GeV}$ in the CM frame.

The signal is extracted by subtracting the $B\overline{B}$ and continuum backgrounds. The continuum contribution is subtracted using the off-resonance data. Dominant $B\overline{B}$ background comes from the π^0 and η decay, which is calibrated from Monte Carlo samples with correction factors in π^0 and η momentum bins. Figure 2 shows the photon energy spectrum in the CM frame after background subtraction. From this we calculate \mathcal{A}_{CP} , correcting possible asymmetry from detector and $B\overline{B}$ background and dilution from $B\overline{B}$ mixing. The measurement of \mathcal{A}_{CP} is performed for photon energy thresholds between 1.7 GeV and 2.2 GeV. For the $E_\gamma^* > 2.1 \text{ GeV}$, we obtain

$$\mathcal{A}_{CP}(\overline{B} \rightarrow X_{s+d}\gamma) = (2.2 \pm 4.0 \pm 0.8)\%, \quad (4)$$

where first uncertainty is statistical and the second is systematic. This result is consistent with the SM prediction and the most precise measurement.

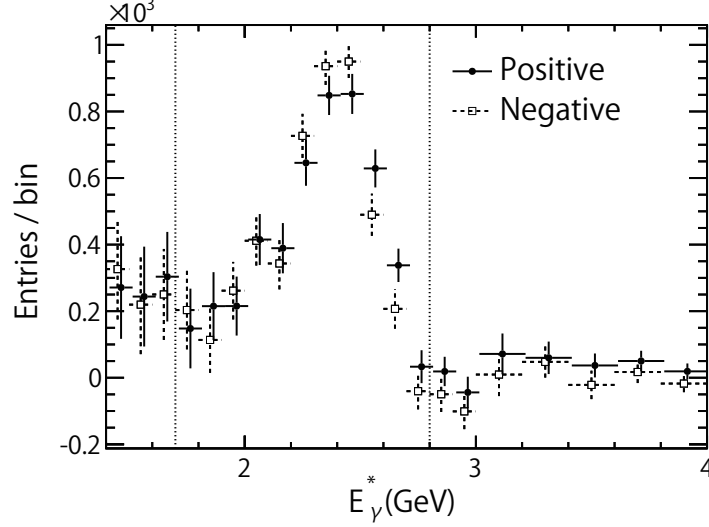


Figure 2: Photon energy spectrum in the CM frame after background subtraction. The positive (circles) and negative (squares) tagged events are shown. Error bars includes statistical and systematic uncertainties.

4 Forward-backward Asymmetry in the $B \rightarrow X_s \ell^+ \ell^-$

The lepton forward-backward asymmetry is defined as

$$\mathcal{A}_{\text{FB}}(q_{\text{min}}^2, q_{\text{max}}^2) = \frac{\int_{q_{\text{min}}^2}^{q_{\text{max}}^2} dq^2 \int_{-1}^1 d \cos \theta \operatorname{sgn}(\cos \theta) \frac{d^2 \Gamma}{dq^2 d \cos \theta}}{\int_{q_{\text{min}}^2}^{q_{\text{max}}^2} dq^2 \int_{-1}^1 d \cos \theta \frac{d^2 \Gamma}{dq^2 d \cos \theta}}, \quad (5)$$

where $q^2 = M_{\ell^+ \ell^-}^2$ and θ is the angle between the $\ell^+ (\ell^-)$ and the B meson momentum in the $\ell^+ \ell^-$ center-of-mass frame in \overline{B}^0 or B^- (B^0 or B^+) decays. For this analysis, a “sum of exclusive” approach is chosen. We reconstruct B meson from dilepton with opposite charge and one of 10 X_s final states, where lepton is a electron or a muon. The inclusive $B \rightarrow X_s \ell^+ \ell^-$ is extrapolated from the sum of 10 exclusive X_s states, assuming \mathcal{A}_{FB} does not depend on the lepton flavor and X_s mass. To reject a large part of the combinatorial background, we require $M_{X_s} < 2 \text{ GeV}/c^2$.

The main background comes from random combinations of two semileptonic B or D decays, which have both large missing energy due to neutrinos, and displaced origin of leptons from B or D mesons. Other background originates from continuum events,

which is suppressed using event shape variables. To efficiently suppress semileptonic and continuum backgrounds, we employ the NeuroBayes.

To examine the q^2 dependence of \mathcal{A}_{FB} , we divide the data into 4 bins of measured q^2 . In order to extract \mathcal{A}_{FB} , maximum likelihood fit to four M_{bc} distributions (positive/negative $\cos\theta$ for electron/muon channel) is simultaneously performed for each q^2 bin. The signal reconstruction efficiency dependence to q^2 and $\cos\theta$ is taken into account. Figure 3 shows the measured \mathcal{A}_{FB} as a function of q^2 . For $q^2 > 10.2 \text{ GeV}^2/c^2$, $\mathcal{A}_{\text{FB}} < 0$ is excluded at the 2.3σ level. For $q^2 < 4.3 \text{ GeV}^2/c^2$, the result is within 1.8σ of the SM expectation. This result is the first measurement of \mathcal{A}_{FB} in inclusive $B \rightarrow X_s \ell^+ \ell^-$.

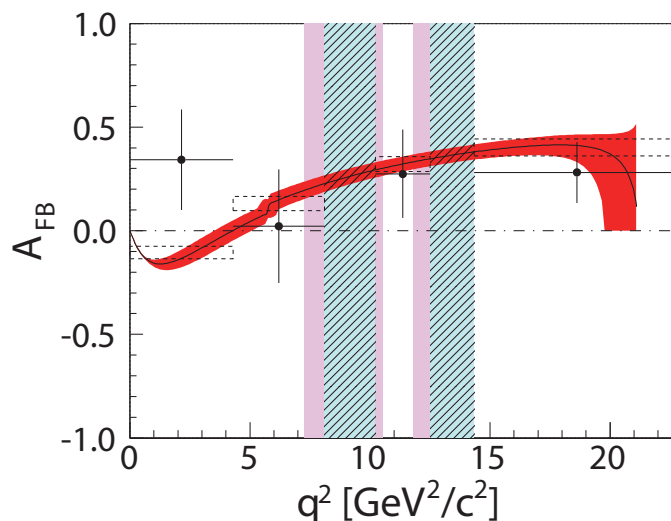


Figure 3: Measured \mathcal{A}_{FB} as a function of q^2 . The curve (black) with the band (red) and dashed boxes (black) represent the SM prediction [5, 6] while filled circles with error bars show the fit results. The J/ψ and $\psi(2S)$ veto regions are shown as teal hatched regions. For the electron channel, the pink shaded regions are added to the veto regions due to the large bremsstrahlung effect.

5 Conclusion

We report precise measurement of branching fraction of the $\overline{B} \rightarrow X_s \gamma$ and CP asymmetry in the $\overline{B} \rightarrow X_{s+d} \gamma$, and first measurement of the forward-backward asymmetry in the $\overline{B} \rightarrow X_s \ell^+ \ell^-$. The results based on the large data sample recorded by the Belle detector at the KEKB e^+e^- collider. All results are compatible with the SM expectation. Analysis about CP asymmetry in the $\overline{B} \rightarrow X_{s+d} \gamma$, and the forward-backward asymmetry in the $\overline{B} \rightarrow X_s \ell^+ \ell^-$ are limited by statistics and thus will be measured

more precisely at Belle II. More precise measurement of branching fraction of the $\overline{B} \rightarrow X_s \gamma$ will be performed with different approach in which the other B meson is fully reconstructed at Belle II.

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